Keeping PACE with the NASA Plankton, Aerosol, Cloud, ocean Ecosystem mission

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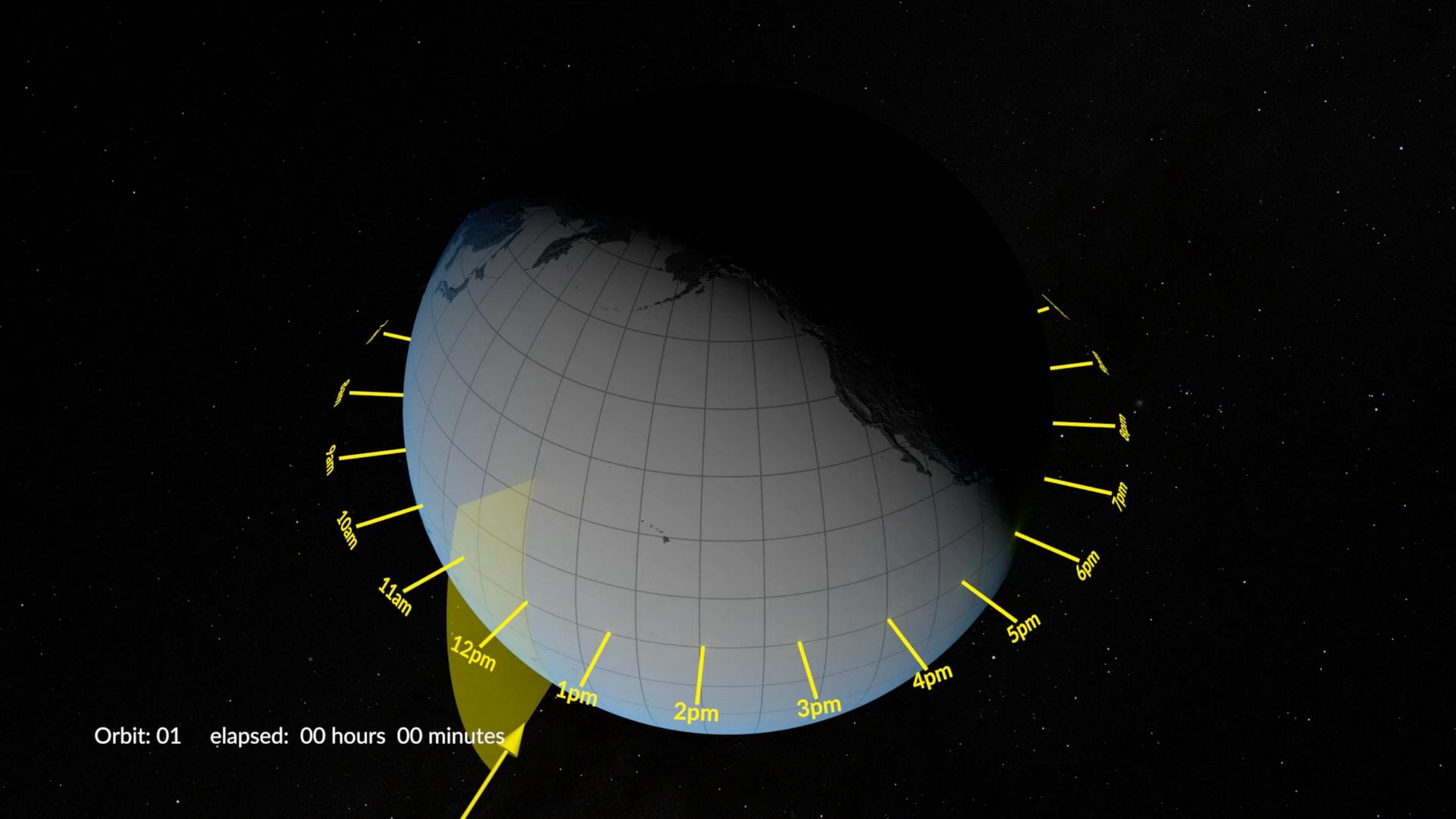
PACE Deputy Project Scientist

[on behalf of Jeremy Werdell, Brian Cairns, and the PACE Project]

BDEC meeting, 9 May 2023

2021 2030 United Nations Decade of Ocean Science for Sustainable Development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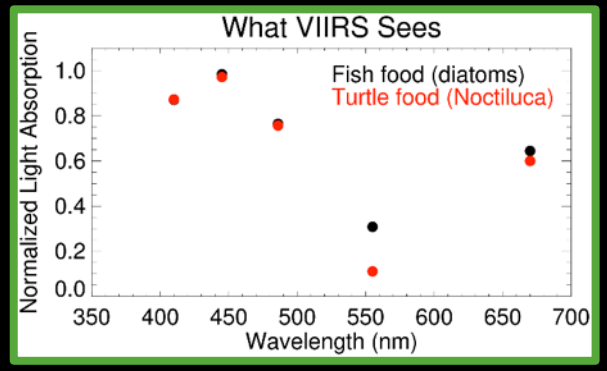
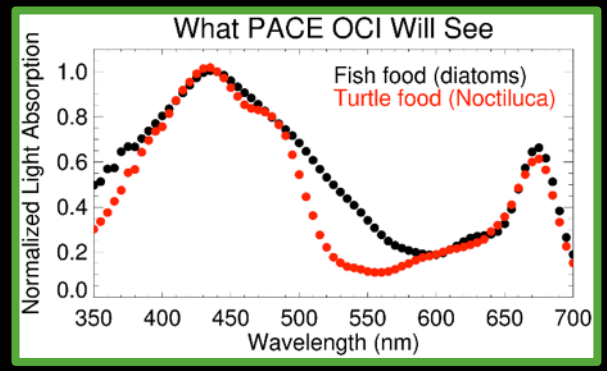
PACE advances

- filling niches that cannot be currently addressed at home or abroad -

Moving from multi-spectral to hyperspectral radiometry is critical for observing aquatic systems





No other current or planned hyperspectral radiometer provides **1-2 day global** coverage

UV & two 2-μm bands realize several atmospheric improvements over heritage instruments

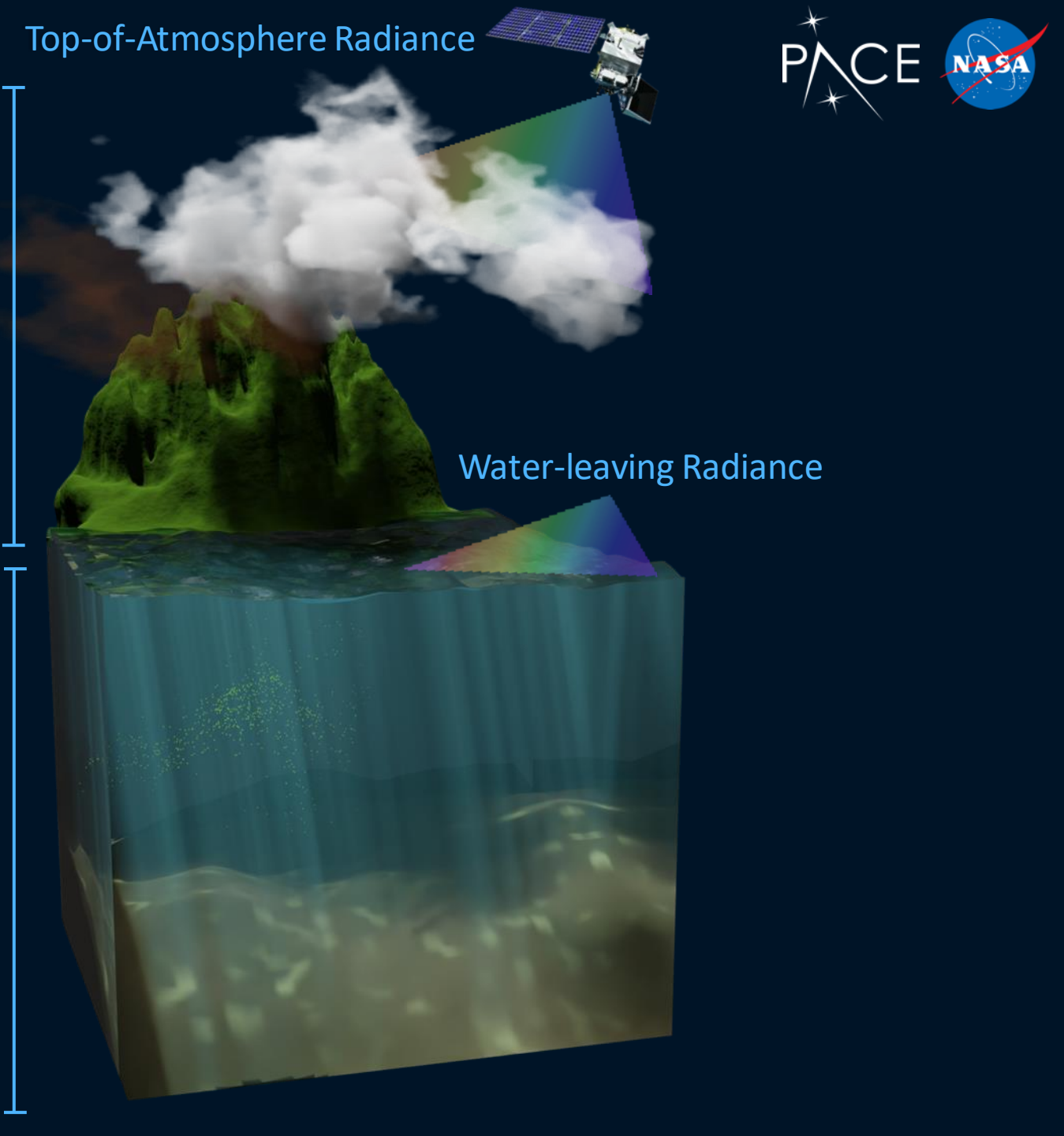
Multi-angle polarimetry adds dimensions of information

Both polarimeters provide excellent proofs of concept for advanced aerosol & cloud retrievals (hello, AOS & MetOP-SG, etc.), as well as for ocean color atmospheric correction

Tilt (Sun glint avoidance) is essential for capturing marine system dynamics

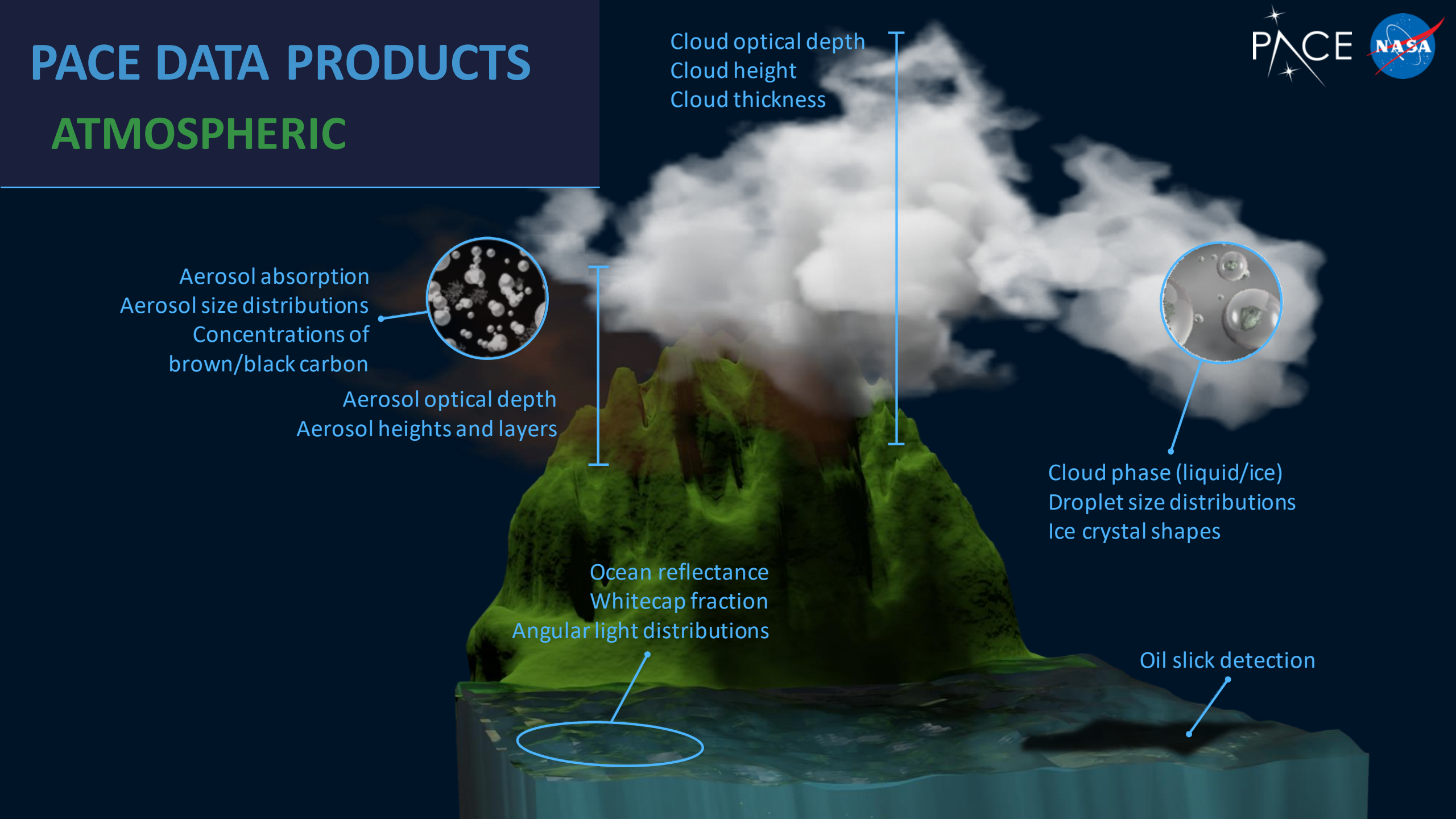
PACE DATA PRODUCTS

ATMOSPHERIC
OCEAN COLOR



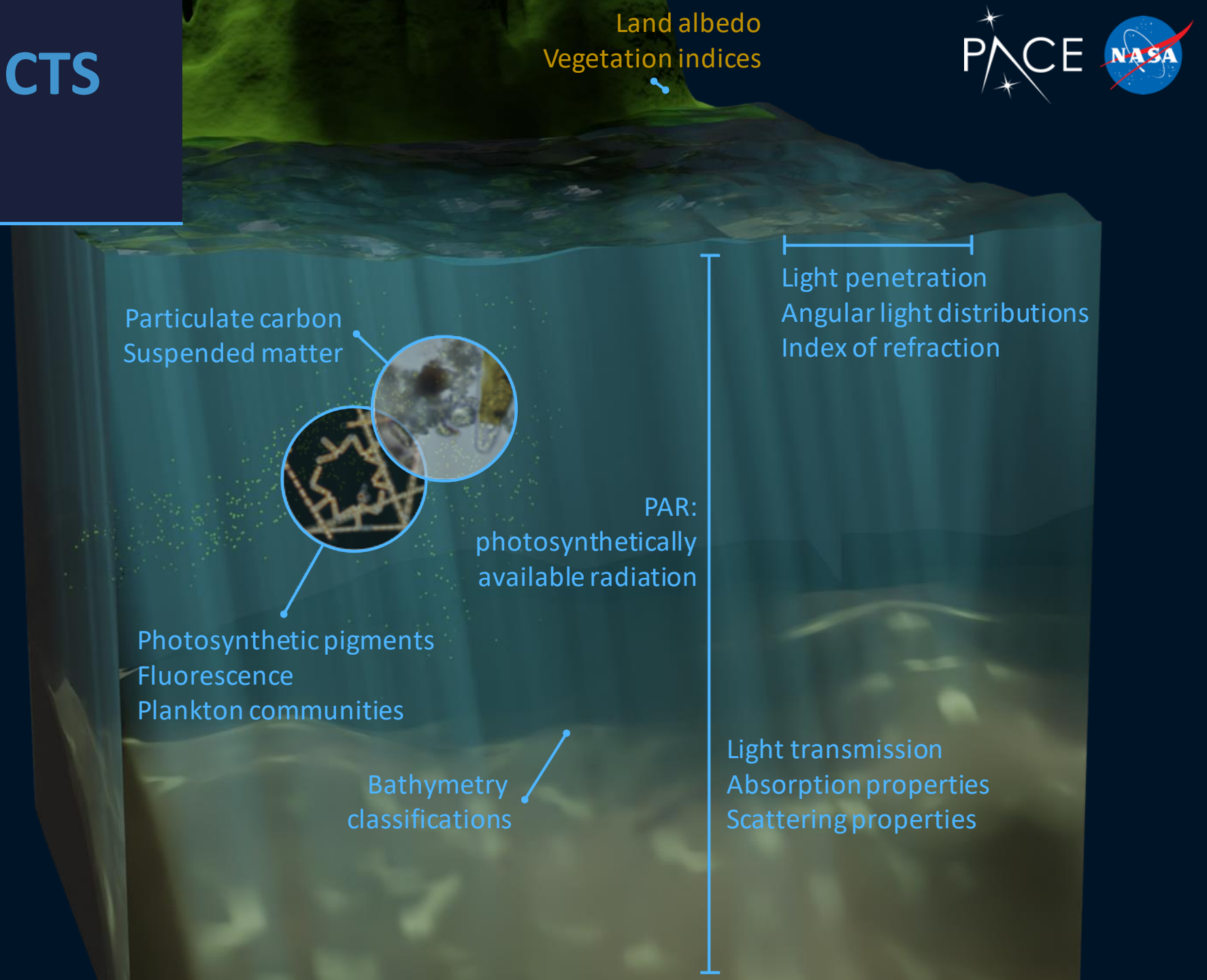
PACE DATA PRODUCTS

ATMOSPHERIC



PACE DATA PRODUCTS

TERRESTRIAL



https://pace.oceansciences.org/data_table.htm

Data Products Table

Calibrated Radiometry and Polarimetry | Ocean Properties to be Produced by OCI | Atmospheric Properties to be Produced by OCI | Land Data Products to be Produced by OCI | Aerosol and Ocean Properties from HARP2 and SPEXone | Ocean Surface Properties from HARP2 | Aerosol and Land Surface Properties from HARP2 and SPEXone | Cloud Properties from HARP2 and SPEXone

Calibrated Radiometry and Polarimetry

Calibrated and geolocated radiometry and polarimetry as observed at sensor.

Product	Description and Use	Units	Availability	Status	Additional Info
Spectral top-of-atmosphere radiances from OCI	Spectral radiance observed at the top of the atmosphere.	W m^{-2} um^{-1} sr^{-1}	Level-1B 1-km at nadir; daily - Level-1C TBD; daily	Standard product	Level-1C draft data format and examples
Spectral top-of-atmosphere radiances and polarimetry from SPEXone	Spectral radiance and polarimetry observed at the top of the atmosphere, for all sensor viewing angles.	Various	Level-1B TBD; daily - Level-1C TBD; daily	Standard product	Level-1C draft data format and examples
Spectral top-of-atmosphere radiances and polarimetry from HARP2	Spectral radiance and polarimetry observed at the top of the atmosphere, for all sensor viewing angles.	Various	Level-1B TBD; daily - Level-1C TBD; daily	Standard product	Level-1C draft data format and examples

Ocean Properties to be Produced by OCI

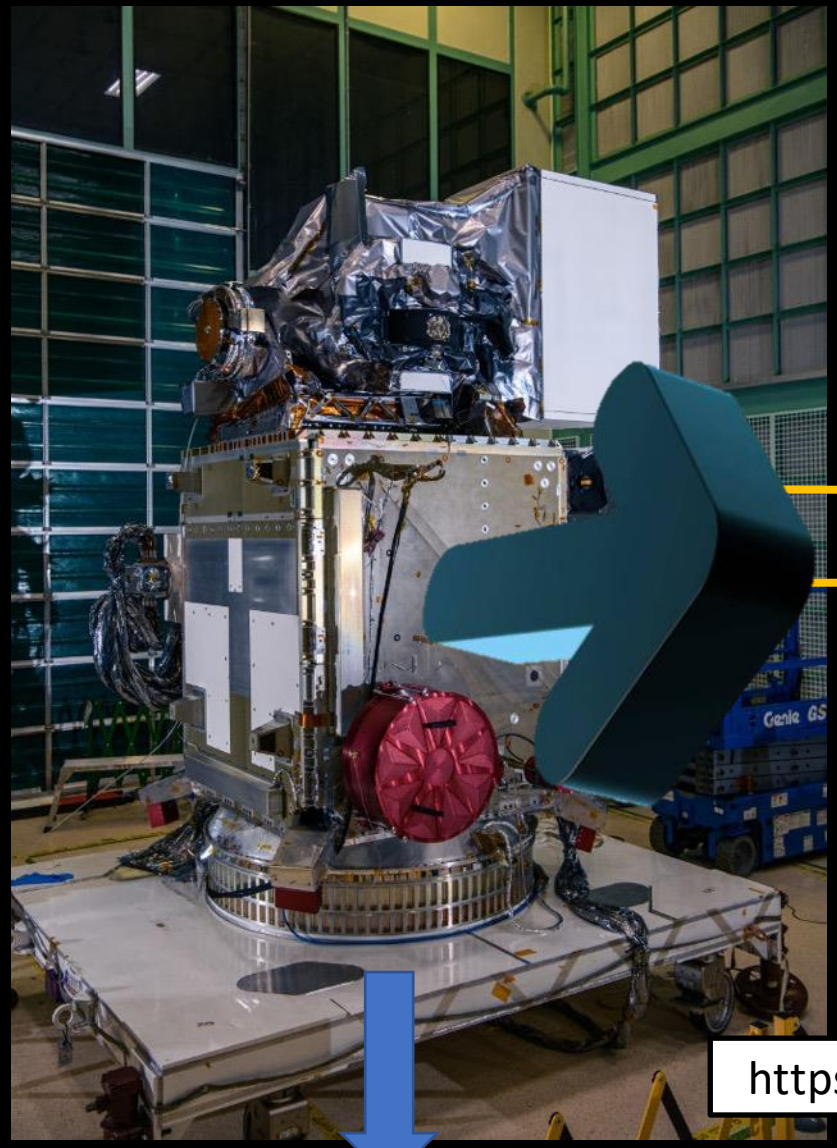
Bio-optical and biogeochemical properties of seawater constituents in the sunlit upper ocean.

Product	Description and Use	Units	Availability	Status	Additional Info
Spectral remote sensing reflectances	Spectral color of the ocean in the ultraviolet-to-near infrared spectral range. Used as input into algorithms to retrieve information about colored dissolved organic matter, phytoplankton, non-algal particles, and other aquatic constituents. Provided in continuous 2.5-nm steps from 350 to 717.5-nm with a resolution (bandwidth) of 5-nm.	sr^{-1}	Level-2 1-km at nadir; daily - Level-3 4-km; daily, 8-day, monthly, annual	Standard product	ATBD SAT members: Boss, Zhai, Krotkov, Chowdhary, Stamnes, Zhang In situ measurement protocols
Spectral diffuse attenuation coefficients	Spectral diffuse attenuation of downwelling irradiance at multiple wavelengths between 350 and 700-nm. Provides indices of water clarity and light penetration.	m^{-1}	Level-2 1-km at nadir; daily - Level-3 4-km; daily, 8-day, monthly, annual	Standard product	ATBD SAT members: Boss, Stramski, Odermatt In situ measurement protocols
Spectral phytoplankton absorption coefficients	Spectral absorption coefficients for total phytoplankton absorption at multiple wavelengths between 350 and 700-nm. Provides information on phytoplankton physiology, abundance, and community composition.	m^{-1}	Level-2 1-km at nadir; daily - Level-3 4-km; daily, 8-day, monthly, annual	Standard product	ATBD SAT members: Twardowski, Stramski, Shuchman, Pahlevan, Siegel, Barnes, Stamnes, Chowdhary In situ measurement protocols
Spectral non-algal particle plus dissolved organic matter absorption coefficients	Spectral absorption coefficients for non-algal particulates and dissolved organic matter at multiple wavelengths between 350 and 700-nm. Provides information on the concentrations of the dissolved component of organic carbon and the detrital (non-algal) component of the particulate assembly.	m^{-1}	Level-2 1-km at nadir; daily - Level-3 4-km; daily, 8-day, monthly, annual	Standard product	ATBD SAT members: Twardowski, Stramski, Barnes, Stamnes, Chowdhary In situ measurement protocols

245 days until launch as of … *today*

what can you expect between now and then (and after)?

since our last meeting … the full observatory was assembled



OCI

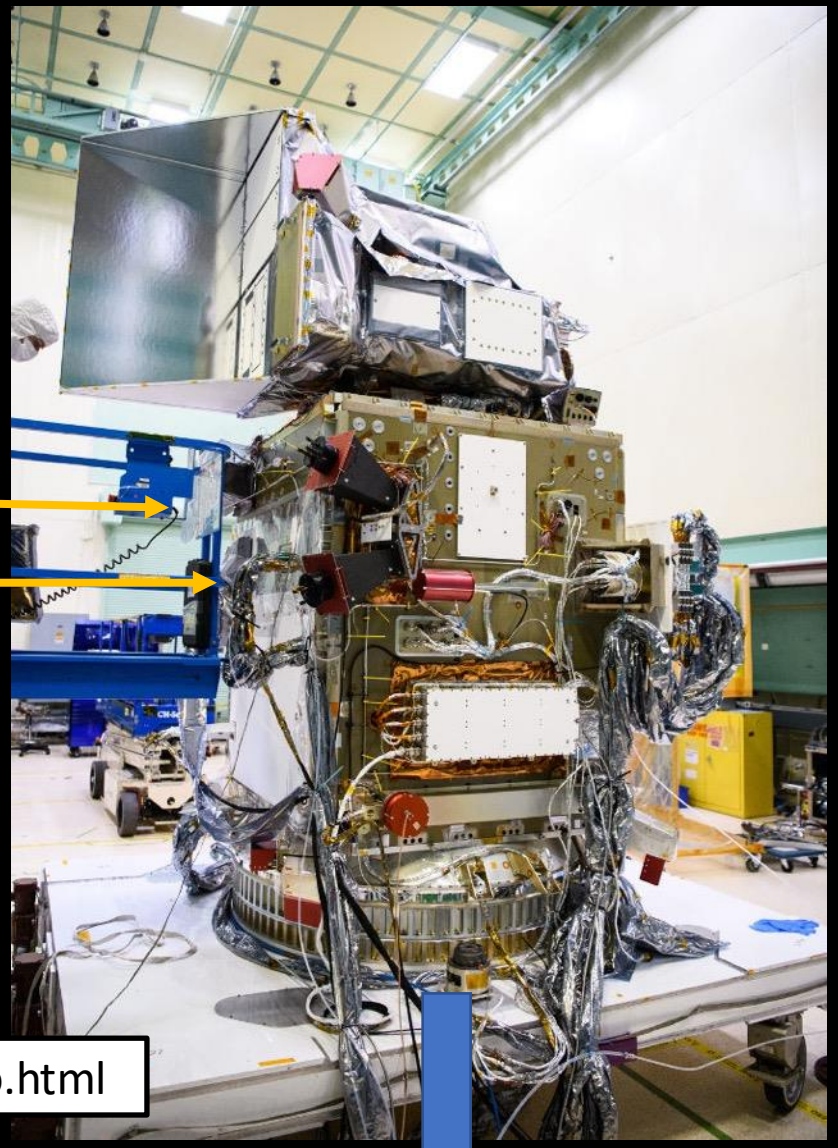
HARP2

nadir (Earth) view

SPEXone

direction of flight

https://espd.gsfc.nasa.gov/pace/video.html



the road to launch …

- completed tests related to launch
  - vibration, acoustic, shock tests
- tests related to the space environment follow
  - thermal vacuum starts ~next week
  - campaign lasts ~2 months
- tests related to end-to-end data flow occurring simultaneously
- delivery to Kennedy Space Center (Cape Canaveral) in early/mid November
- ~46 days of launch site operations

what to expect after launch …

- 60 days of in-orbit commissioning (IOC)
- 1st 30 days
  - spacecraft checkout & maneuvers
  - power on the instruments
- 2nd 30 days
  - instrument checkout
  - coordinated observations last 10 days

- SDS ”officially” distributes data after 60 days
  - heritage & required products (Rrs, AOT, clouds)
  - note: Lt, Rrs at 2.5 (1.25) nm resolution
  - advanced / polarimetric to TBD follow

algorithm implementation

- process follows the Science Data Product Implementation Plan

- Science Operations Board (Project, HQ, DAAC) oversees the process and considers scientific value & resource requirements

- stepwise approach for algorithm implementation, testing, evaluation, & maturation

- reach out to Jeremy Werdell, Bryan Franz, any Proj Sci deputy or lead to start

Name	Products	Status
AVW	AVW	SOB approved
PhytoC	[phytoplankton carbon]	SOB approved
Café	NPP, growth rates	SOT ongoing; finalizing implementation
ZTT	adg, aph, a, bbp, bb	SOT ongoing; finalizing orig. implementation
RemoTAP	aerosol loading & micro-physics, surface properties	SOT ongoing; testing within SDS using simulated datasets
FastMAPOL	aerosol loading & micro-physics, ocean properties	SOT ongoing; testing within SDS using simulated datasets & aircraft data
AquaVerse	water quality variables (Chl, TSS, CDOM, PC)	SOT ongoing; imple-mentation underway

Name	Products	Status
PACE-MAPP	aerosol loading & micro-physics, ocean properties, cirrus cloud mask	SOT ongoing; tested on aircraft data; code implementation
polarimeter cloud products	multiple algorithms for liquid clouds, ice clouds, cloud top thermodynamic phase index, COT, CTH, cloud fraction, cloud physical thickness	SOT ongoing; evaluating first code drop
SDP	13 [Chl + accessory pigments]	SOT ongoing; imple-mentation underway
PAR	planar PAR above/below the surface, scalar PAR below the surface, average cosine	SOT ongoing; begin implementation
LS2-3SAA	adg, aph, a, bbp, bb	SOT ongoing; begin implementation
Unified Aerosol Algorithm	AOD, FMF, SSA in certain conditions	SOT ongoing; awaiting code
ocean surface refractive index	ocean surface refractive index	SOT ongoing; awaiting code

simulated data available

OCI (PyTOAST: Python Top Of Atmosphere Simulation Tool, medium/low-fidelity):

- version 9 now available
- 1 full day (21 March 2022) including:
  - Level-1A, -1B, -1C, -2, -3 bin, -3 map
  - ocean color, aerosols, clouds
- L2 and beyond are NOT for scientific use; but, OK for testing input/output processing systems, code readers, file specs, etc.

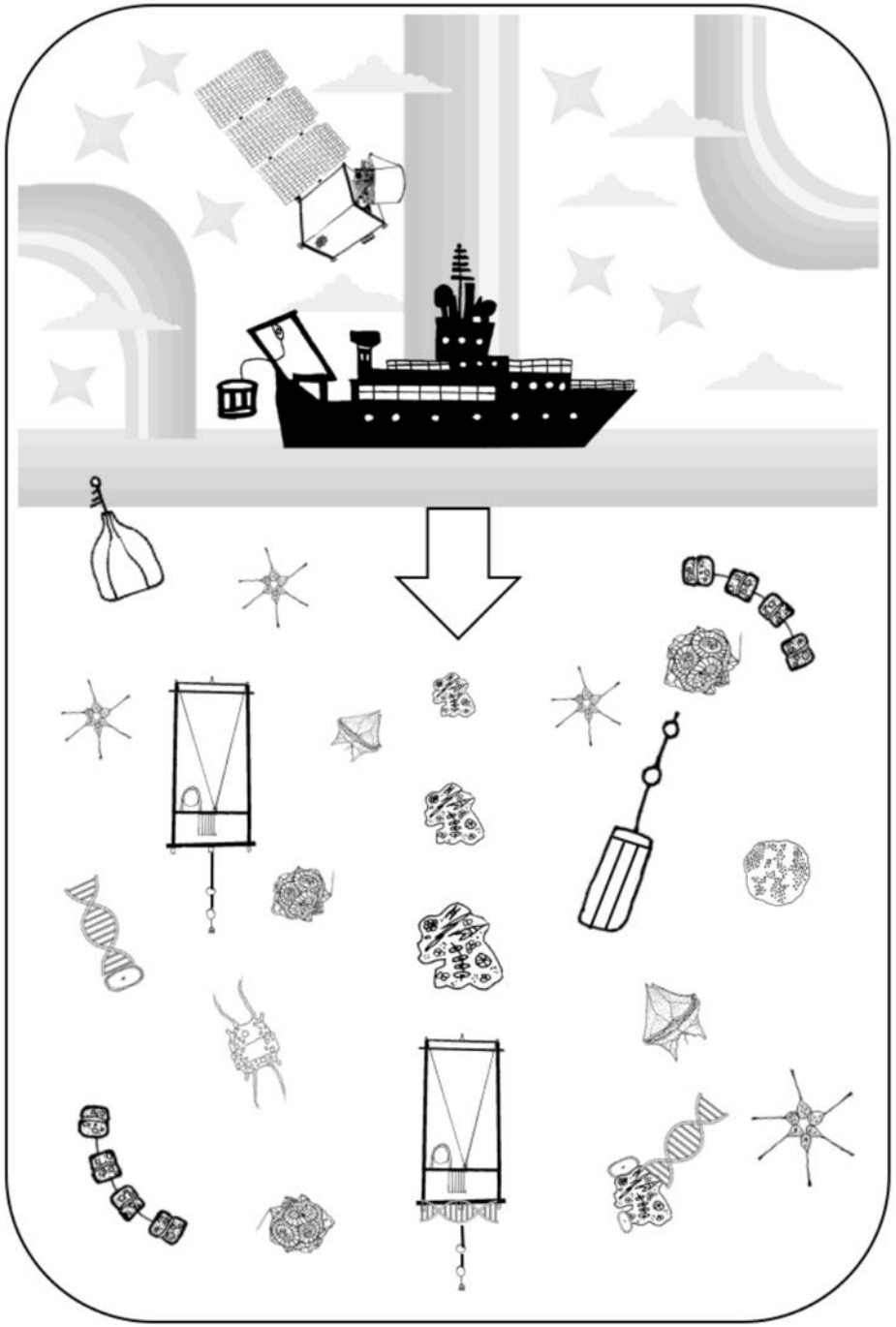
polarimeters:

- Level-1C for both HARP2 and SPEXone

System Vicarious Calibration (SVC)

both projects preparing for launch & beyond

(1) HyperNAV	(2) MarONet
OSU, SeaBird Scientific	U.Miami, NIST
radiometric float - small, portable - profiling - long-duration - COTS legacies	radiometric buoy - large, 20’ container - 3 fixed arms - long-deployment - MOBY legacy
multi-site operations	migration to Perth, Australia
test deployments conducted (e.g., Crete)	test deployments conducted (e.g., Lanai)



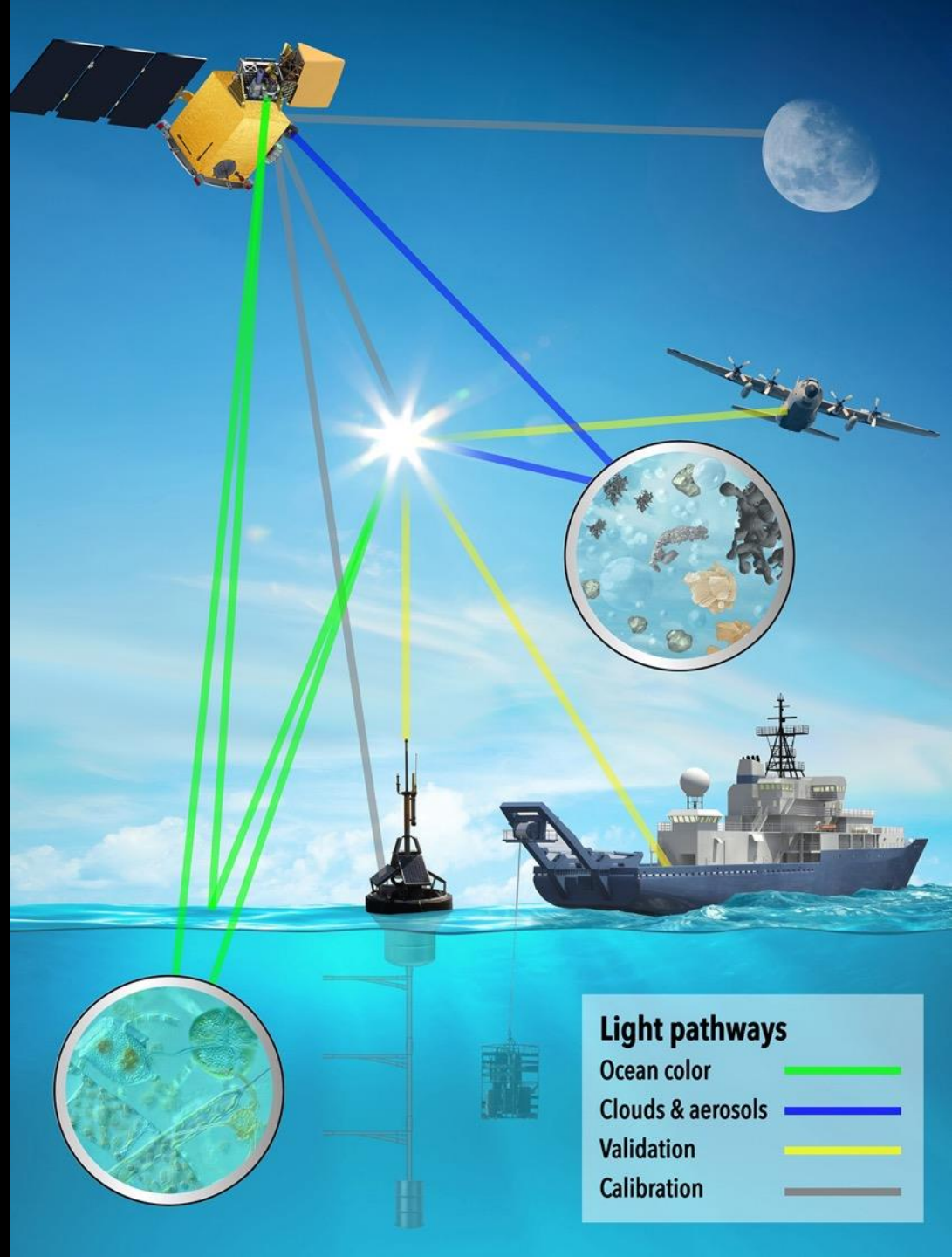
post-launch validation activities

PACE Validation Science Team (PVST)

- ROSES-22 late amendment solicitation
- proposals were due May 5
- selection ~fall 2023
- in the field after first light (~spring 2024)

PACE Post-launch Airborne eXperiment (PACE-PAX)

- aircraft (+ in-/on-water TBD)
- planning underway (docs hosted @ *pace.oceansciences.org/campaigns.htm*)
- direct & proxy measurements
- US west coast, Sep 2024
- synergy with PVST anticipated
- not competed



PACE Postlaunch Airborne eXperiment (PACE-PAX)

An airborne field mission devoted to validation of NASA PACE observations

Deploying two aircraft, each flying out of their home base:

- CIRPAS Twin Otter (Marina, CA) – Direct (in situ) aerosol, cloud measurements
- NASA ER-2 (Palmdale, CA) – Remote, PACE Proxy, measurements

Coordination of ground & ocean target overflights and satellite underflights supported with a Validation Traceability Matrix (VTM), Bayesian search theory, and a strong weather forecasting team

3-27 September 2024, 60 flight hours

PACE-PAX validation objectives
1. Validate new retrieval properties
2. Assess spatial and temporal scale impact on validation
3. Validate in a narrow swath
4. Validate radiometric and polarimetric properties
5. Target specific geometries, season, and time of day
6. Focus on specific processes or phenomena

Instrument/Team	Role	Lead PI	Institution
AirHARP	PACE/HARP2 polarimetry proxy	J. Vanderlei Martins	UMBC
HSRL-2	Aerosol/cloud/ocean Lidar	T. Shingler / J. Hair	NASA LaRC
PICARD ARC	PACE/OCI spectrometer proxy	James Jacobson	NASA ARC
PICARD GSFC	PACE/OCI spectrometer proxy (data)	Kerry Meyer	NASA GSFC
PRISM	PACE/OCI spectrometer proxy	David R. Thompson	JPL
RSP	Multi-angle polarimeter reference	B. Cairns / K. Sinclair	NASA GISS
SPEX Airborne	PACE/SPEXone polarimetry proxy	Otto Hasekamp	SRON
Twin Otter	Aerosol/cloud in situ instruments	Anthony Bucholtz	NPS
LARGE	Aerosol/cloud in situ instruments	Luke Ziemba	NASA LaRC
ISARA	In situ instrument synergy activity	Snorre Stamnes	NASA LaRC
LI-Nephelometer	Aerosol phase functions	Adam Ahern	NOAA
Weather team	Weather & aerosol, cloud forecasting	Rei Ueyama	NASA ARC
ESPO	Earth Science Project Office	Erin Czech	NASA ARC

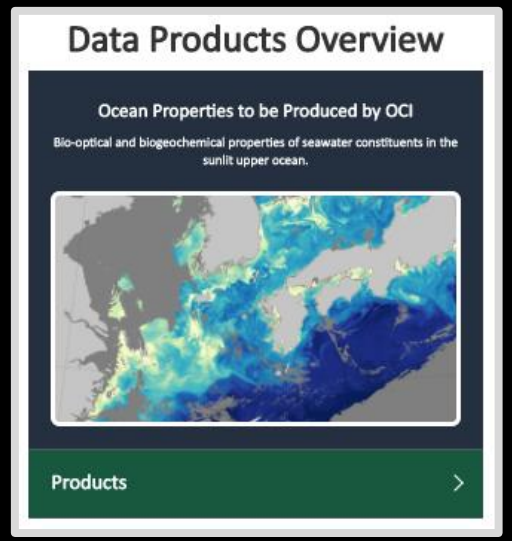
Leadership team:

Kirk Knobelspiesse, Mission Scientist, NASA GSFC
Brian Cairns, Deputy Mission Scientist, NASA GISS
Ivona Cetinić, Deputy Mission Scientist, NASA GSFC

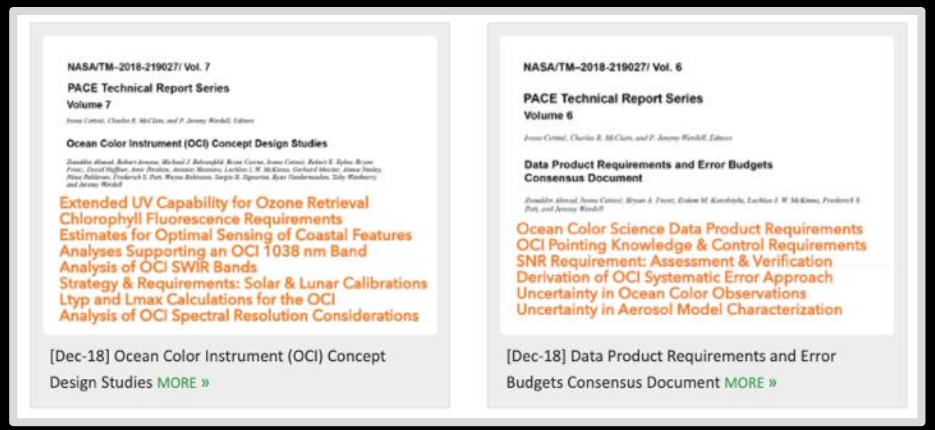
pace.oceansciences.org/campaigns.htm

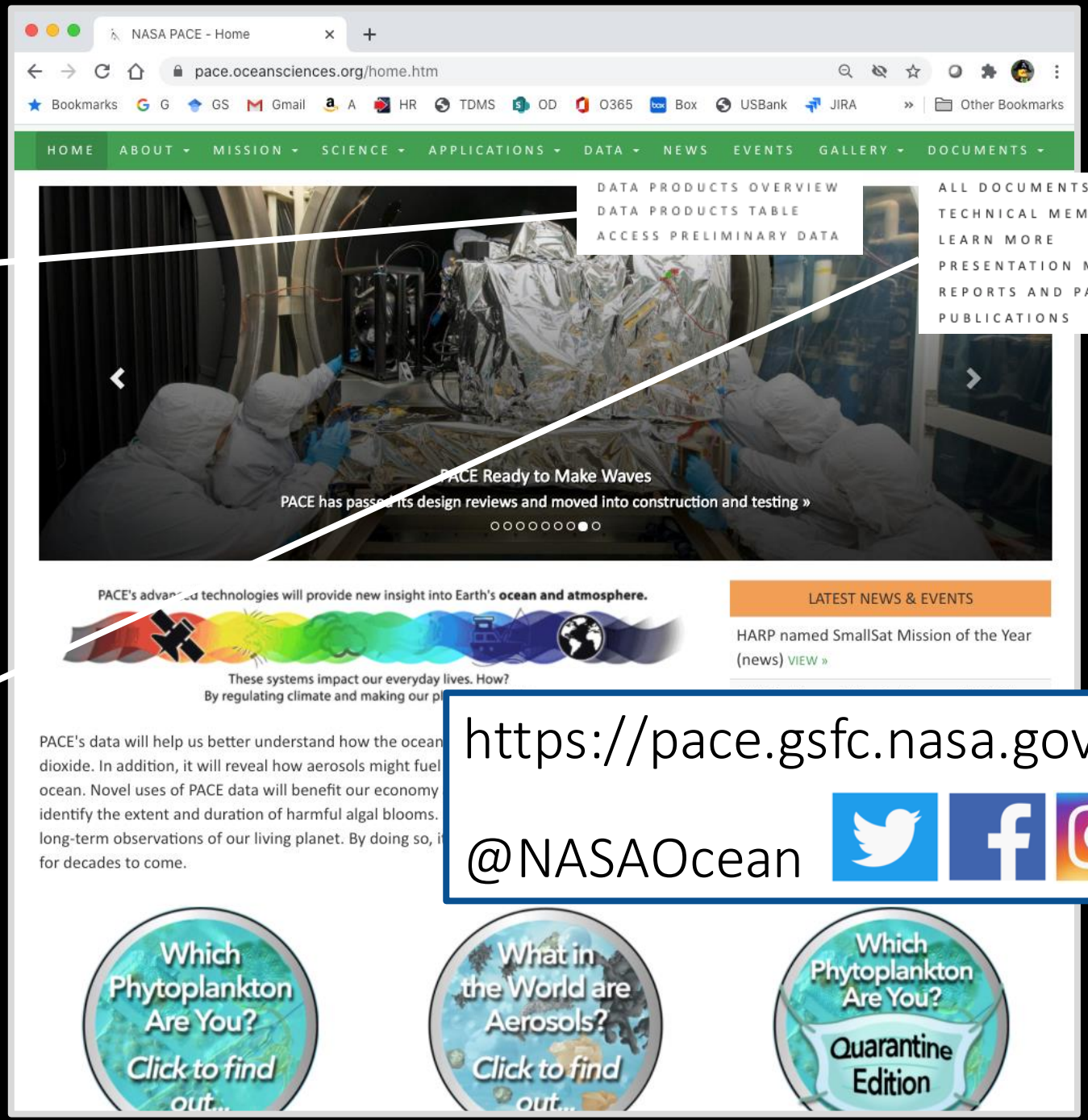
resources & useful info

data product descriptions + access to simulated data & characterizations



PACE technical memos & other documents





https://pace.gsfc.nasa.gov

@NASAOcean


PACE
Plankton, Aerosol, Cloud, ocean Ecosystem

NASA Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission

PACE will extend **key systematic ocean color, aerosol, & cloud (& terrestrial) climate data records**.

PACE will reveal the **diversity of organisms fueling marine food webs** & how ecosystems respond to change.

Looking at the ocean, clouds, and aerosols together will improve knowledge of the roles each plays in our planet.

Key characteristics:

- 9 January 2024 launch on a Falcon 9 from KSC
- 676.5 km altitude
- Polar, ascending, Sun synchronous orbit; 98° inclination
- 13:00 local Equatorial crossing
- 3-yr design life; 10-yr propellant
- 6-9 hrs latency (on average; full range ~3-24 hrs)

The PACE Ocean Color Instrument (OCI):

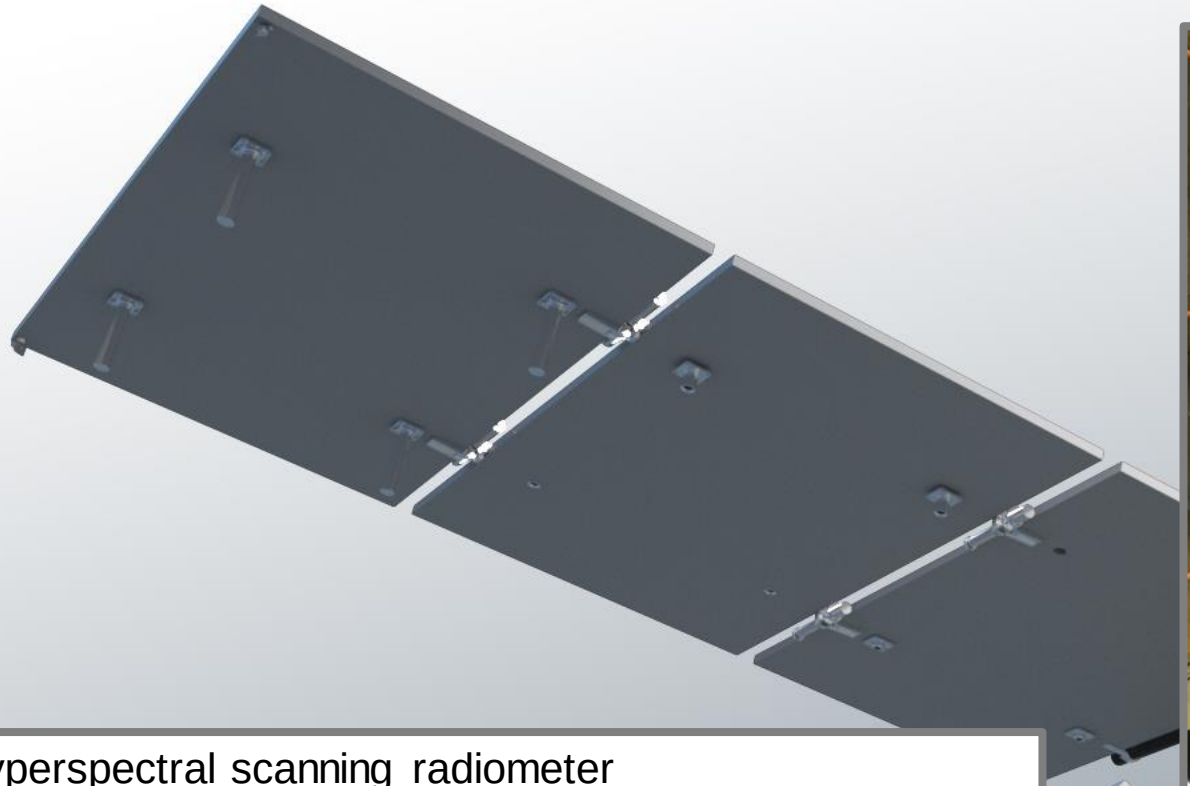
- 340-890 nm @ 5 nm resolution in 2.5 nm spectral steps
- Plus 940, 1038, 1250, 1378, 1615, 2130, & 2250 nm
- 2-day global coverage; 1-km^2 @ nadir; ±20° fore/aft tilt
- *Performance driven by ocean color science requirements*

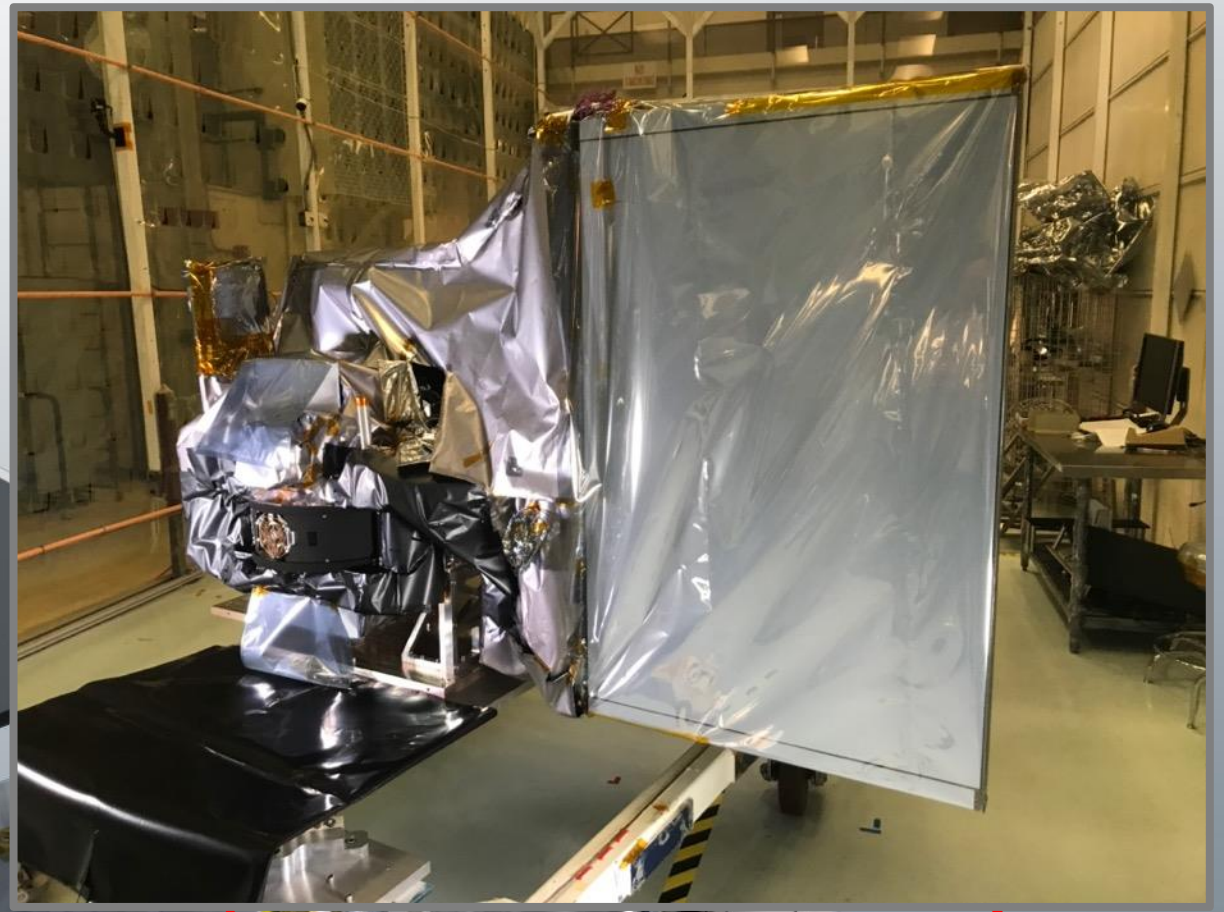
https://pace.gsfc.nasa.gov
@NASAOcean

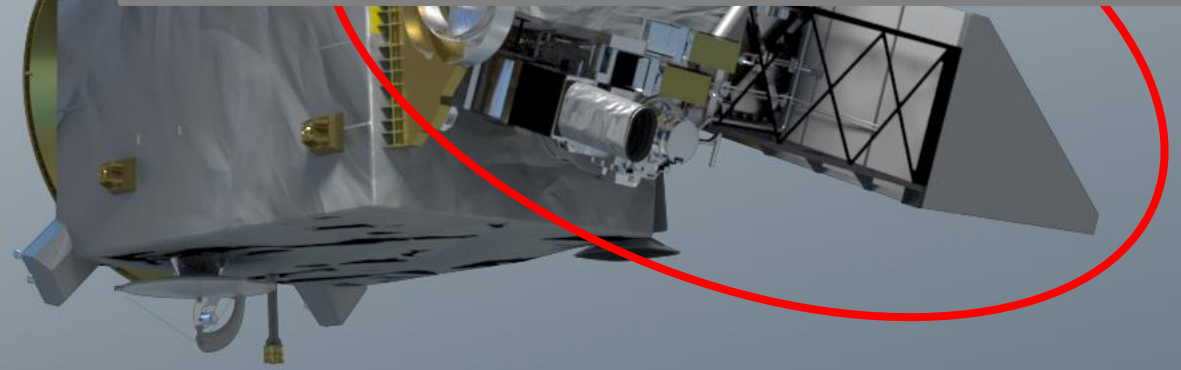
2 contributed multi-angle polarimeters:

- **HARP-2 (UMBC)**
  4 visible-NIR bands
  Wide swath; 2.5 km @ nadir
  Hyper-angular
  Cloud capabilities beyond OCI

- **SPEXone (SRON/Airbus)**
  Hyperspectral UV-NIR
  Narrow swath; 3 km @ nadir
  5 angles
  Aerosol capabilities beyond OCI







- hyperspectral scanning radiometer
- (320) 340 – 890 nm, 5 nm resolution, 2.5 nm steps+
- plus, 940, 1038, 1250, 1378, 1615, 2130, and 2250 nm
- *single science pixel to mitigate image striping*
- 1 – 2 day global coverage
- ground pixel size of 1 km^2 at nadir
- ± 20^o fore/aft tilt to avoid Sun glint
- twice monthly lunar calibration
- daily on-board solar calibration
- <0.5% total system error for VIS-NIR
- SNRs optimized for ocean color science
- simulated top-of-atmosphere data available

+ with 1.25 nm steps in several spectral regions

* developed primarily for mechanical processing assessments

UMBC Hyper Angular Rainbow Polarimeter (HARP-2)

Update

- Fully integrated on the spacecraft in Oct 2022
- 1 day of simulated data available online

- Excellent for cloud droplet size and ice particle shape/roughness retrievals
- *Provides cloud capabilities beyond those required of OCI*
- *Wide swath matches OCI, offering potentially improved atmos. correction*

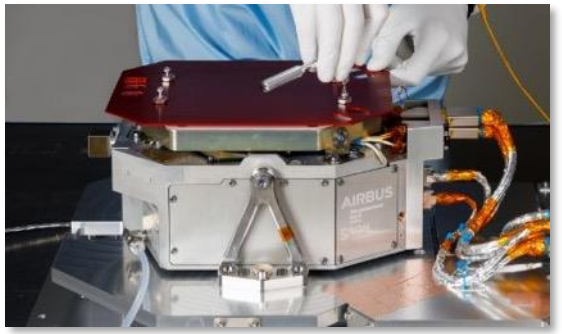
	HARP-2	SPEXone
UV-NIR range	440, 550, 670, 870 nm	Continuous from 385-770 nm in 5 nm steps
SWIR range	None	None
Polarized bands	All	Continuous from 385-770 nm in 15-45 nm steps
Number of viewing angles [degrees]	10 for 440, 550, 870 nm; 60 for 670 nm [spaced over 114°]	5 [-57°, -20°, 0°, 20°, 57°]
Swath width	±47° [1556 km at nadir]	±4.5° [106 km at nadir]
Global coverage	2 days	30+ days
Ground pixel	3 km	2.5 km
Heritage	AirHARP, Cubesat	AirSPEX

- Excellent for aerosol characterization
- *Addresses aerosol climate objectives beyond those required of OCI*

OCI + SPEXone + HARP2

- Greater information content than any current instrument suite for ocean color, aerosol, & cloud observations
- New data products: ocean color from multi-angle polarimetry, wind speed, etc.

SRON/Airbus Spectro-polarimeter for Planetary Exploration (SPEXone)



Update

- Fully integrated onto the spacecraft in June 2022
- 16 orbits of simulated data available online